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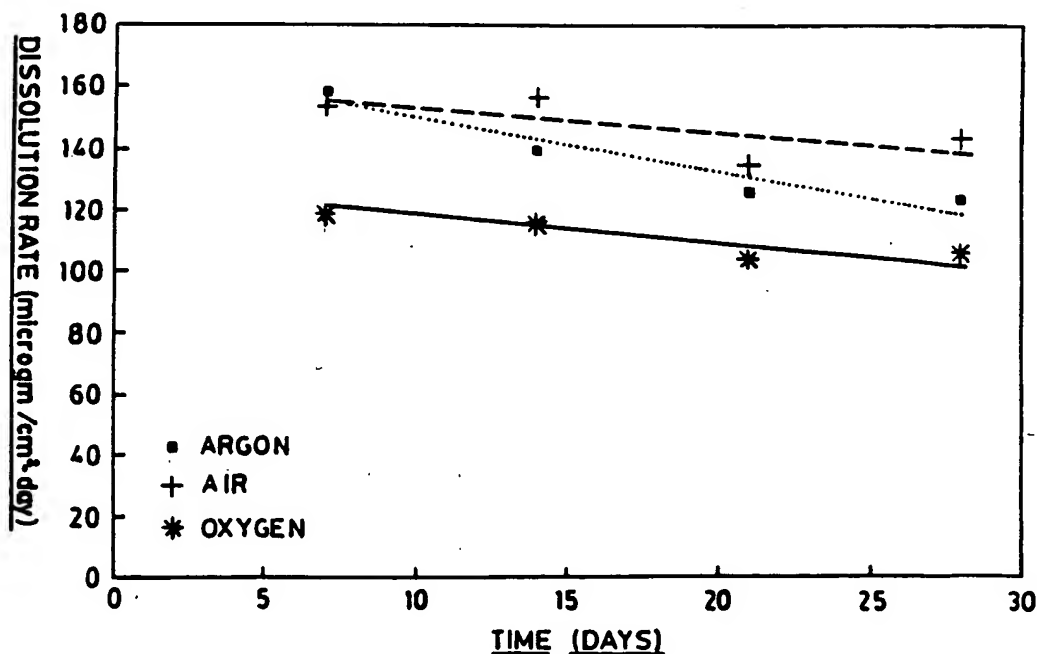
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(54) Title: PROCESS FOR MAKING A DURABLE, BIOABSORBABLE FIBER



(57) Abstract

There is provided a process for forming bioabsorbable glass. In the first step of this process, a glass batch containing from about 40 to about 80 mole percent of phosphorous compound and from about 3 to about 40 mole percent of iron compound is provided. Thereafter, the glass batch is melted while under an enriched oxygen atmosphere. Fiber may be formed from the glass melt. Alternatively, the glass melt may be formed in a glass article which, after remelting, then may be made into a fiber.

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## PROCESS FOR MAKING A DURABLE, BIOABSORBABLE FIBER

### Field of the invention

A process for preparing a durable, bioabsorbable glass fiber in which a glass batch is melted in the presence of an enriched oxygen atmosphere during glass melting and fiber is thereafter formed.

### Background of the prior art

Phosphate glass compositions are well known to those skilled in the art. However, fibers made from these phosphate glass compositions often have poor physical properties. Thus, for example, U.S. patent 4,604,097 of Graves et al. disclose a spun or drawn fiber consisting primarily of calcium oxide and phosphorous pentoxide. In column 5 of the patent, the patentees disclose that the average tensile strength of the fibers prepared in the experiment of Example I was only 37,100 pounds per square inch.

It is an object of this invention to provide fiberizable phosphate glass compositions with superior mechanical properties and chemical durability.

It is another object of this invention to provide bioabsorbable glass fibers with superior mechanical and durability properties.

### Summary of the invention

In accordance with this invention, there is provided a process for forming bioabsorbable glass. In the first step of this process, a glass batch containing from about 40 to about 80 mole percent of phosphorous compound and from about 3 to about 40 mole percent of iron compound is provided. Thereafter, the glass batch is melted while under an enriched oxygen atmosphere.

Brief description of the drawing

The present invention will be more fully understood by reference to the following detailed description thereof, when read in conjunction with the attached drawing, wherein like reference numerals refer to like elements, and wherein:

Figure 1 is a graph showing the durability properties of the glass compositions of some of the examples of this patent application.

Description of the preferred embodiments

In the first step of the preferred process of this invention, the materials comprising the glass batch are charged into a mixer. In general, a sufficient amount of phosphorous compound is charged so that the resulting glass formed from the batch contains from 40 to 80 mole percent of phosphorous pentoxide ( $P_2O_5$ ). Although the custom in the glass art is to refer to the constituents in the form of oxides, the oxides per se need not be used in producing the glass. A sufficient amount of a suitable phosphorous compound is charged to the mixer so that the batch contains, on an equivalent basis, from about 40 to about 80 mole percent of phosphorous, expressed as phosphorous pentoxide. By way of illustration, suitable phosphorous compounds include phosphorous pentoxide, phosphoric acid, calcium phosphate, ammonium hydrogen phosphate, and the like. Other metaphosphates and pyrophosphates may also be used. Thus, e.g., synthetic apatite, tricalcium phosphate, and other calcium phosphate compounds having a Ca/P atomic ratio of 1.4-1.75 may also be used. See, e.g., U.S. patent 4,376,168 of Takami et al., the disclosure of which is hereby incorporated by reference into this specification.

In one preferred embodiment, a sufficient amount of the phosphorous compound is charged to the mixer so that the

batch contains, on an equivalent basis, from 55 to 75 mole percent of phosphorous pentoxide.

In one embodiment, a portion of the phosphorous material charged to the mixer is replaced by silica. In addition to the phosphorous compound, a sufficient amount of iron compound is added so that the batch contains, on an equivalent basis, from 3 to 40 mole of iron, expressed as percent of  $\text{Fe}_2\text{O}_3$ . Suitable iron compounds include, e.g., ferrous oxide ( $\text{FeO}$ ), ferric oxide ( $\text{Fe}_2\text{O}_3$ ), calcium ferro compounds, etc.

In one embodiment, the iron compound used is ferric oxide, and some of the ferric oxide is replaced by alumina.

In addition to the phosphorous compound and the iron compound, the batch in the mixer may be comprised of from 0 to 50 mole percent (and preferably 5 to 50 mole percent) of at least one compound of a divalent cation selected from the group consisting of compounds of calcium, zinc, magnesium, and mixtures thereof. One may use a mixture of two of such cations such as, e.g., calcium and zinc or calcium and magnesium.

In addition to the phosphorus compound and the iron compound, the batch in the mixer may also comprise from 5 to 15 mole percent of an alkali metal compound. Any suitable source of alkali metal cation may be used. Thus, for example, one may use the oxides of sodium, potassium, lithium, and mixtures thereof. Thus, e.g., the carbonate, the nitrate, etc. of the alkali metal cation(s) may also be used. Thus, e.g., one may use sodium phosphate, sodium metaphosphate, potassium oxide, potassium carbonate, sodium carbonate, and the like.

Inasmuch as the batch in the mixer will be used to prepare a bioabsorbable fiber, it is preferred that no material which is toxic to human beings be used in the batch. Thus, for example, it is preferred that no lead or

lead-containing materials be present in the batch.

Commercially available reagents may be used in the process of this invention. Thus, e.g., calcium oxide may be used in the form of limestone. Magnesium oxide may be used in the form of dolomite. Soda ash made by the Solvay process may be used. Other alkalis may be introduced into the batch by feldspar, phonolite, or nepheline-syenite. Potassium oxide may be introduced into the glass as potassium carbonate. Small amounts of alumina may be introduced into the glass as a subsidiary component of limestone; if a higher alumina content is required, use may be made of aluminum oxide, aluminum hydroxide, feldspar, kaolin, phonolite, etc.

By way of illustration, one may use a glass comprised of 25 mole percent of calcium oxide ( $\text{CaO}$ ), 68 mole percent of phosphorous pentoxide, and 7 mole percent of iron oxide.

By way of further illustration, one may use a glass comprised of 25 mole percent of calcium oxide, 65 mole percent of phosphorous pentoxide, 3 mole percent of alumina, and 7 mole percent of iron oxide. Alternatively, one may use a glass comprised of 25 mole percent of calcium oxide, 68 mole percent of phosphorous pentoxide, 2 mole percent of alumina, and 7 mole percent of iron oxide.

By way of yet further illustration, one may use a glass comprised of 11 mole percent of calcium oxide, 79 mole percent of phosphorous pentoxide, and 10 mole percent of iron oxide.

In one preferred embodiment, the glass contains at least about 55 mole percent of phosphorous pentoxide.

Once a homogeneous glass batch with the desired composition has been obtained in the mixer, it may be discharged to a glass former, in which it is melted. The glass former is comprised of a glass-melting furnace. Thus, by way of illustration, one may use a pot furnace, a day tank, a continuous tank furnace, an all-electric furnace, and the

like.

The glass is melted in an atmosphere which contains at least 50 volume percent of oxygen. It is preferred that the atmosphere in which glass batch is melted contain at least 60 volume percent of oxygen. It is more preferred that the atmosphere contain at least 70 volume percent of oxygen. In an even more preferred embodiment, the atmosphere contains at least 80 volume percent of oxygen. In one especially preferred embodiment, the atmosphere consists essentially of oxygen.

The temperature used for the glass melting will depend upon the composition of the glass batch being melted. In general, the temperature should be such that the viscosity of the melt is less than 1,000 poise. In one embodiment, the glass melting temperature is greater than about 1,100 degrees Centigrade. In one embodiment, the glass melting temperature is greater than about 1,200 degrees Centigrade.

Fiber may be made from the glass melt produced by the process of this invention by means well known to those skilled in the art. Thus, one may prepare continuous fibers with diameters from 3 to 500 microns. It is preferred that the continuous fibers have diameters of from 3 to 50 microns. In one embodiment, the diameter of the continuous fibers is from 10 to 30 microns.

Alternatively, one may prepare staple fibers, blown fibers, microfibers, and the like.

Fiberization processes are well known to those skilled in the art. Thus, as is disclosed in J. G. Mohr et al.'s "Fiber Glass," (Van Nostrand Reinhold Company, New York, 1978), one may make fiber from applicants' glass compositions by a "Mineral Wool" process (see pages 8-9), by a steam-blown process (see pages 9-10), by a flame attenuation process (see pages 10-11), by a spinning process (see pages 10-11), by a rotary process (see pages 12-14), etc.

In one preferred embodiment, the glass is made into



continuous filament. For this purpose, one may use the marble melt process, the direct melt process, or the Strickland process for making continuous filament; see, e.g., pages 190-200 of the Mohr et al. book.

Both the glass made by the process of this invention, and the fiber made by the process of this invention, have improved durability properties. The durability of the compositions of the invention may be evaluated in a constant temperature bath. The preferred testing apparatus is a Fisher Versa-Bath S Shaker Bath, model number 236, which is described on pages 100- 101 of the "Fisher 88" catalog (Fisher Scientific, 711 Forbes Avenue, Pittsburgh, Pennsylvania). In determining the durability, this bath is maintained at a temperature of 37 degrees centigrade and is operated at a shaking speed of 60 strokes per minute, each stroke being 2.0 inches long.

The fibers made by the process of this invention have an improved average tensile strength. The average tensile strength of a glass fiber may be determined in accordance with a conventional procedure on a laboratory tensile testing unit; thus the tensile test units sold by Instron Corporation of 100 Royall Street, Canton, Massachusetts may be used to test the fiber. In the test, individual samples of 10, 20 and 30 millimeter gage lengths are used; and each of them are attached to a paper cutout using a drop of standard household glue (Elmer's Glue All, Borden Inc., Columbus, Ohio) at the points of contact of the fiber with the paper. Testing of the samples is done immediately after preparation and drying of the glue; the samples are loaded at a constant strain rate of 10 millimeters per minute. The average of the tensile strength of twenty fiber samples is the average tensile strength for the fiber.

Fibers made by the process of this invention have an improved Young's Modulus. The Young's modulus and the

tensile strength of the fiber may be determined in accordance with A.S.T.M. Standard Test D3379-75, entitled "Standard Test Method for Tensile Strength and Young's Modulus for High Modulus Single Filament Materials." The moduli of twenty fiber samples is determined, an average is calculated, and it is reported as an average Young's modulus.

The following examples are presented to illustrate the claimed invention but are not to be deemed limitative thereof. Unless otherwise specified, all parts are by weight and all temperatures are in degrees Centigrade.

#### Examples

##### Example 1

Eleven parts of calcium oxide, 79 parts of phosphorous pentoxide, and 10 parts of ferric oxide were ground in a mortar and pestle until a uniform glass batch was obtained. The mixed batch was then premelted in an alumina crucible at 600 degrees Centigrade. After the premelting, the crucible was transferred to a furnace at 1,300 degrees Centigrade where it was subjected to an atmosphere consisting of oxygen and said temperature of 1,300 degrees Centigrade for about 1 hour. The crucible was then removed from the furnace, and the glass specimen was cast in a graphite mold maintained at 700 degrees Centigrade. The dissolution rate of the glass specimen was determined gravimetrically. The glass specimen (which was about 1 inch long and about 0.25 inch in diameter) was immersed in 25 milliliters of a phosphate buffered solution with a pH of 7.4, and the glass specimen/phosphate buffered solution was kept at 37degrees Centigrade in a shaker bath.

The dissolution rate of the glass specimen was obtained by removing the glass sample from the bath at a specified time, weighing the glass sample, and dividing the weight loss over the surface area and the immersion time.

At a time of 10,000 minutes, the glass of this example had a dissolution rate of about  $8.2 \times 10^{-8}$  grams per square centimeter per minute.

#### Example 2-3

The procedure of Example 1 was substantially followed, with the exception that the oxygen atmosphere of Example 1 was replaced either with an air atmosphere (Example 2) or an argon atmosphere (Example 3). The glass of Example 2 had a dissolution rate of about  $10.7 \times 10^{-8}$  grams per square centimeter per minute. The glass of Example 3 had a dissolution rate of about  $11.0 \times 10^{-8}$  grams per square centimeter per minute.

The dissolution rates for the experiments of Examples 1, 2, and 3 may be expressed in terms of micrograms per square centimeter per day. The dissolution rate of the glass of Example 1 (oxygen atmosphere) was 118.4 micrograms per square centimeter per day. The dissolution rate of the glass of Example 2 (air atmosphere) was 153.0 micrograms per square centimeter per day. The dissolution rate of the glass of Example 3 (argon atmosphere) was 157.5 micrograms per square centimeter per day.

#### Examples 4-19

The procedure of Examples 1-3 was substantially followed, with the exception that the glass samples were maintained in the phosphate buffer solution for different times before their durabilities were tested. The results of these experiments are shown graphically in Figure 1.

One may make fibers by the process of this invention which have a maximum dimension of from about 3 to about 100 microns and, preferably, from about 10 to about 30 microns. The fiber may have any cross-sectional shape, but it is preferred that it be circular.

One may prepare a composite comprised of the fiber of this invention and a polymeric material. The polymeric material may be a bioabsorbable polymer. See, e.g., U.S.

patents 4,329,743 and 4,411,027 of Alexander (polylactic acid), 4,141,087, 4,140,678, and 4,052,988.

One may form a composite material with the fiber of this invention and epoxy resin.

It is to be understood that the aforementioned description is illustrative only and that changes can be made in the apparatus, the ingredients and their proportions, and in the sequence of combinations and process steps as well as in other aspects of the invention discussed herein without departing from the scope of the invention as defined in the following claims.

What is claimed is:

1. A process for preparing a bioabsorbable glass fiber, comprising the steps of:

(a) providing a glass batch comprised of from 40 to 80 mole percent of phosphorous (expressed as phosphorous pentoxide), from 3 to 40 mole percent of iron (expressed as ferric oxide), from 0 to 50 mole percent of a compound of a divalent cation, and from 0 to 15 mole percent of an alkali metal compound, wherein said compound of a divalent cation is selected from the group consisting of compounds of calcium, zinc, magnesium, and mixtures thereof;

(b) heating said glass batch to a temperature sufficient to cause said glass batch to form a melt while simultaneously contacting said glass batch to an atmosphere comprised of at least 50 volume percent of oxygen, thereby producing a composition which has been contacted with an enriched-oxygen atmosphere; and

(c) forming a fiber from a said composition which has been contacted with an enriched-oxygen atmosphere.

2. The process as recited in claim 1, wherein said enriched-oxygen atmosphere consists essentially of oxygen.

3. The process as recited in claim 2 wherein said glass batch is comprised of from about 3 to about 40 mole percent of ferric oxide.

4. The process as recited in claim 3, wherein said glass batch is comprised of from about 5 to about 50 mole percent of at least one of said compounds of a divalent cation.

5. The process as recited in claim 4, wherein said divalent cation is calcium.

6. The process as recited in claim 5, wherein said glass batch is comprised of at least about 55 mole percent of phosphorous pentoxide.

7. The process as recited in claim 6, wherein said glass

batch is melted at a temperature in excess of about 1,100 degrees Centigrade.

8. The process as recited in claim 6, wherein said glass batch is melted at a temperature in excess of about 1,200 degrees Centigrade.

9. The process as recited in claim 1, wherein said glass batch is comprised of from about 55 to about 75 mole percent of phosphorous compound (expressed as phosphorous pentoxide).

10. The process as recited in claim 1, wherein said glass batch is comprised of silica.

11. The process as recited in claim 1, wherein said glass batch is comprised of alumina.

12. The process as recited in claim 1, wherein said glass batch is comprised of from about 5 to about 14 mole percent of alkali metal compound.

13. The process as recited in claim 12, wherein said alkali metal is selected from the group consisting of sodium, potassium, and mixtures thereof.

14. The process as recited in claim 13 wherein said alkali metal compound is selected from the group consisting of sodium oxide, potassium oxide, and mixtures thereof.

15. The process as recited in claim 13, wherein said alkali metal compound is selected from the group consisting of sodium carbonate, potassium carbonate, and mixtures thereof.

16. The process as recited in claim 13, wherein said alkali metal compound is selected from the group consisting of sodium nitrate, potassium nitrate,, lithium nitrate, and mixtures thereof.

17. The process as recited in claim 1, wherein said glass batch is comprised of about 79 mole percent of phosphorous pentoxide, 11 mole percent of calcium oxide, and 10 mole percent of ferric oxide.

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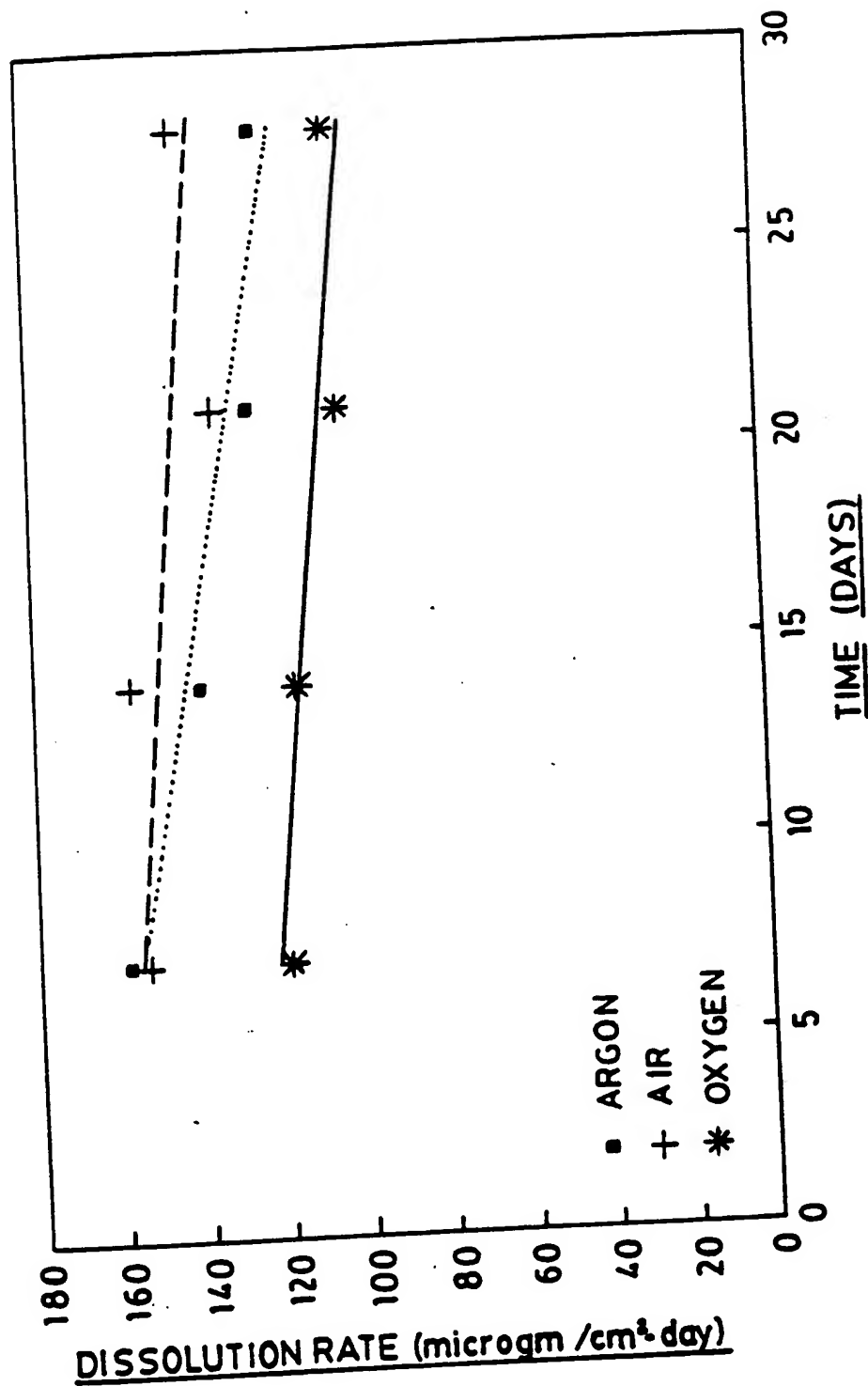


FIG. 1

# INTERNATIONAL SEARCH REPORT

International Application No. PCT/US91/08161

## I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) \*

According to International Patent Classification (IPC) or to both National Classification and IPC  
 IPC(5): C03C 3/16  
 US CL: 501/44,45; 264/65

## II. FIELDS SEARCHED

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Classification System

Classification Symbols

US

501/45,44, 264/65

Documentation Searched other than Minimum Documentation  
 to the extent that such Documents are included in the Fields Searched \*

## III. DOCUMENTS CONSIDERED TO BE RELEVANT \*

Category *	Citation of Document, ** with indication, where appropriate, of the relevant passages **	Relevant to Claim No. **
X	US,A, 4,847,219 (Boatner et al) 07 July 1989 (see col. 4, lines 9-12; col. 3, lines 29-33 and claim 1)	1-2
V	US,A, 3,897,236, (Roberts) 29 July 1975 (see claim 1 and col. 4, lines 40-42)	3-9, 12-17
Y	US,A, 4,182,437, (Roberts et al), 08 Jan. 1980 (see col. 5, lines 40-54 and claim 1)	10-11

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"A" document defining the general state of the art which is not considered to be of particular relevance

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## IV. CERTIFICATION

Date of the Actual Completion of the International Search

07 February 1992

Date of Mailing of this International Search Report

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Signature of Authorized Officer

Susan E. Hollenbeck